Article

Effect of thermal oscillation on the quality and yield of white onion in the Culiacan Valley, Sinaloa

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Abstract

Onion is one of the most important food crops worldwide. However, the production of this vegetable is conditioned by environmental factors such as temperature. The present research work was carried out in the autumn-winter cycle 2016-2017 and aimed to study the effect of temperature on the content of fiber, protein, ash and °Brix in onion. The capacity of this crop to carbon capture was also analyzed. Regarding the thermal oscillation, the coefficient of determination was 0.84; that is, this dependent variable explains 84% of the behavior of the bulb weight. Likewise, it was found that the correlation between the weight and diameter of the onion was 0.943, that is, 94% of the behavior of one variable depends on the other, where the value of the slope indicates that for each centimeter of diameter of the onion, it increases 98.6 g in weight. With respect to the bromatological analysis, no statistically significant differences were found. Likewise, although there were no statistically significant differences between the treatments in reference to the fixation of carbon dioxide, a higher concentration was observed in the treatment that was carried out in lower temperature conditions, having a value of 1.56 CO_2 (t CO_2 eq ha^{-1}).

Keywords: bulb formation, carbon capture, plant development.

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Introduction

Onion (*Allium cepa* L.) is the second most important food vegetable worldwide after tomato with 96 773 819 t produced globally (FAOSTAT, 2018). In Mexico in 2018, 50 167.78 ha were harvested with a production of 1 572 607.99 t and an average production of 31.35 t ha^{-1} according to data from the Agrifood and Fisheries Information Service (SIAP, 2018). Where Sinaloa, the same year, harvested 1 962.85 ha, producing 53 513.22 t with an average yield of 27.26 t ha^{-1} (SIAP, 2018). Likewise, agriculture in Sinaloa has suffered great damage in recent years due to extraordinary meteorological phenomena generated largely by the effect of climate change, which is due in part to agricultural activities that involve the emission of greenhouse gases. Thus, one of the main factors that influence the formation of the onion bulb are: length of day, temperature and variety of the crop (Lancaster *et al*., 1996; Brewster, 2008).

Likewise, according to FAO, agriculture can contribute to reducing greenhouse gas emissions by carrying out, among other activities, the use of more effective crop varieties, organic soil management, conservation agriculture and agroforestry systems, reducing the emission of greenhouse gases, because according to this organization, well-managed pasture and cropland can sequester significant amounts of carbon, as 40% of the biomass of the land, and with it biological carbon, is directly or indirectly managed by farmers, foresters or pastoralists.

Based on the above, the objective of this study was to determine the yield and quality of the white onion bulb after being established at different planting dates and temperatures, in addition to determining the content of soluble solids, protein, fiber, ashes and analyzing the carbon capture potential of the onion crop.

Material and methods

Location and conditions of experimental areas

The study was carried out in the autumn-winter cycle 2016-2017, under drip irrigation conditions, on a property belonging to the sindicatura of Quilá, Culiacan Valley, Sinaloa, located at 24° 27’ 27. 64’’ north latitude, 107° 16’’ 1.45’’ west longitude from the Greenwich Meridian and an altitude of 40 m, the climate of the region is BSo(h,) w(e), described as dry steppe climate (B) with a precipitation ratio between temperature less than 22.9 °C (BSo), a very warm thermal regime with an average annual temperature of 26.8 °C and the coldest month temperature of 18. 6 °C (h’), where the average annual rainfall is 525.8 mm (García, 1988).

Figure 1 shows the daily behavior of the maximum average temperature, minimum average temperature, average average temperature and the thermal oscillation that occur from the first transplant to the harvest. In all cases, it is observed that at the beginning of the period all the thermal parameters start with a downward trend until reaching the middle of the period, where the ascent begins again. The thermal behavior throughout the cycle is important because the effect that the different thermal parameters have on the development of the onion will depend on the planting date.

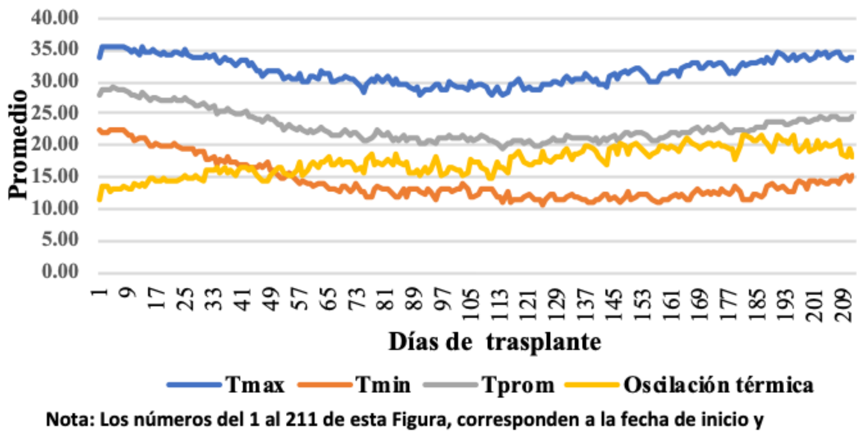

Figure 1. Temperature behavior during the development of onion crop. Elaboration with data from CONAGUA

Type of soil

Some physicochemical characteristics of the soil where the experiment was carried out were determined. Electrical conductivity was determined by the saturation extract method (Aguilar *et al*., 1987). pH was determined using a potentiometer (Aguilar *et al*., 1987). The texture of the soil was calculated using the Bouyoucus hydrometer method (Aguilera and Martínez, 1980). The method for bulk density was by the test tube. The soil where the study was conducted was clay-sandy loam textured with 33.96% clay, 6% silt and 60.04% sand, with a pH of 5.7 and a bulk density of 1.35 g cm^{-3}.

Soil preparation, seedling transplantation and fertigation

The ground was prepared by plowing 30 cm deep, after three cross-harrowing and leveled with a plank to break the lumps of soil. Subsequently, seedbeds 1.6 m wide were formed. In each bed six lines of plants were formed with a separation of 12 cm between them. The distance between plants was 12 cm arranged in a triangular pattern. The experiment was performed under drip irrigation conditions, using tape (Rivulis®) with droppers at 20 cm apart, 16 mm in diameter, thickness of 0.2 and water consumption of one liter per hour per dropper.

Three tapes were used on each bed. The onion hybrid used was 'Carta Blanca' (Nunhems®) of short days with white bulb, round shape and physiological maturity at 170-175 days after sowing. The seedling was produced using polyethylene trays with Kekkila® (Vantaa, Finland) substrate. The transplant was performed when they were 4 mm thick and the germination nodules were approximately 20 cm tall. With this method, onion of uniform shape and size is obtained. The source of each nutrient and the dose of each of them are shown in Table 1.

Table 1. Source and doses of the fertilizers ha^{-1} applied for the development of the onion.

Source	Formulation	Fertilizer (kg)	N	Nitrate NO_3^-	Ammonium NH_4^+	P P_2O_5	K	Ca	Mg	S
Urea	46-00-00	20	9.2	0	0	0	0	0	0	0
Monopotassium phosphate	0-52-34	75	0	0	0	39	25.5	0	0	0
Potassium nitrate	12-00-46	75	9	9	0	0	34.5	0	0	0.9
Calcium nitrate	15-00-00-30 (CaO)	100	15	15	0	0	0	30	0	0
Magnesium nitrate	11-00-00-16 (Mg)	175	19.25	19.25	0	0	0	0	28	0
Ammonium phospho-nitrate	33-04-00	450	148.5	74.25	74.25	18	0	0	0	0
Ammonium sulfate	21-0-0-24 (S)	50	0	0	10.5	0	0	0	0	12
Phosphoric acid	0-52-0	50	0	0	0	26	0	0	0	0
Potassium sulfate	0-0-52-17	75	0	0	0	0	39	0	0	12.75
	Calculated		200.95	117.5	84.75	83	99	30	28	25.65
	Required		200	58.47	42.17	80	100	30	27	25
	Difference		0,95	0	0	3	-1	0	1	0.65

Measurement of the onion plant

The onion plants were harvested when 70% of these in each of the treatments presented leaf folding, which is an indicator that the crop has reached physiological maturity, therefore the rest of the leaves of the plants were manually folded. Two days later the plants were removed from the ground and placed on it to complete the sealing of the bulb neck. The following variables were measured: equatorial diameter of the bulb with a graduated vernier (cm) (Truper ®, Mexico), soluble solids content (°Brix) by a handheld refractometer VEE GEE BX-2 (43003), bulb weight (g) by an analytical balance (Sartorius®).

Bromatological analyses

The estimation of the fixed carbon was made from the proximal chemical composition of each structure. This chemical composition was determined by bromatological analyses specified in the Association of Official Analytical Chemists (AOAC, 1999), which included contents of protein, fiber and ashes. To determine the protein content, the Kjendhal methodology was used by means of a digester and Buchi distiller (Caruso *et al*., 2014).

Calculations were made using the formula % N= (14.01) (ml sample-ml blank) (NHC1)/(sample weight) (10). Where: 14.01= milliequivalent nitrogen; NHC1= normality of hydrochloric acid; ml sample= ml of HCl 0.1N spent in the distillate of each sample; and ml blank= ml of HCl 0.1N spent with the distillate of the blanks.

The fiber was counted using the Ankom bag method by applying neutral detergent fiber solution (FND). The calculation was made using the formula % FND= 100 (W_3-(W_1Xc))/W_2. Where: W1= weight of the bag; W2= sample weight; W3= weight of the dry bag with fiber after extraction; and C= correction blank (final dry weight) divided by the weight of the initial blank. The ash collection was made in Gooch crucible crucibles in a Novatech® Muffle (500 °C, 3 h) and the final weight of the ashes was taken as a reference.

Atmospheric carbon fixation

To determine the percentage corresponding to carbon in each compound, the following formulas were used: % C= PMC/PMDC∗100 1); CT= (% C)∗(gCM)/100) 2); EqCO_2= (CT∗44)/12 3). Where: % C= percentage of carbon corresponding to each compound (24 protein and 72 for fibre); PMC= molecular weight of the carbon contained in each compound determined from empirical formula; PMDC= molecular weight of the empirical formula of each compound (protein 75 g mol^{-1}, fiber 162 g mol^{-1}); CT= total carbon; gCM= grams of the compound (protein, fiber) in the sample; PS= dry weight of the sample; EqCO_2= CO_2 equivalents; the determination of the fixed carbon is presented in ton of CO_2 equivalents per hectare (t CO_2 eq ha^{-1}) (Pérez *et al*., 2007).

Experimental design and statistical analysis

An experimental design of random complete blocks was established, evaluating the behavior of the onion ‘Carta Blanca’ subjected to five planting dates with different temperatures (treatments; T1: November 7; T2: November 15; T3: November 22; T4: November 29 and T5: December 6), each with four blocks or repetitions. Each block consisted of a bed 100 meters long, where in each of the beds the treatments were distributed randomly by means of the command= rand. Subsequently, each of the random numbers was ordered hierarchically by the formula= rank (B3, B$3:B$7).

For the selection of the useful plot (PU) or sampling unit of each of the treatments, the formula= round (rand ()∗(20-1) + 1) was used. In this way the spreadsheet provided a number from 1 to 20 for each treatment, which represented one meter long in the bed of the treatment which was designated as PU. From each PU the previous parameters were counted and measured in all onion plants.

Data analysis

Initially, the original bulb weight (g) data did not meet the assumptions of normality and homoscedasticity, so they were transformed with the standard square root function ($\dot{x} = \sqrt{x}$). Where $\dot{x}$= transformed value; and x= original value. This transformation is used when the variance is proportional to the mean. In addition, the means previously transformed were inverted to means of original data by the inverse function with ($x = \dot{x}^2$). After the transformation, the assumptions were fulfilled by the tests of Shapiro-Wilk and Bartlett, proceeding with ANOVA and Tukey ($p \leq 0.05$).

Likewise, the original data of weight and diameter of bulb (g), (mm) were subjected to an analysis of correlation and a simple linear regression. The Kruskall-Wallis nonparametric statistics and the Dunn medians comparison ($p\leq 0.05$) with the original data of soluble solids (°Brix) were used, because these did not meet the assumptions mentioned before by the original form and data transformation. For the data from the bromatological analysis and that of atmospheric CO_2 fixation, the assumptions of normality and homoscedasticity were analyzed to later perform the ANOVA and the Tukey mean comparison test ($p\leq 0.05$). On the other hand, with the data of weight and diameter of the onion, a correlation analysis was performed observing that there is a relationship between these variables. The linear regression analysis was based on an equation of the relationship between an independent variable and a dependent variable. The analyses were performed with the Xlstat statistical package (Addinsoft, 2019).

Results and discussion

Weight of the bulb

The yield was represented by the weight of the onion bulb, which presented a statistically significant difference ($p\leq 0.05$). It was found that the onions that were transplanted on December 6 (late date) had on average less development (T5= 153.19 g), while those that were planted (early date) had a higher bulb weight (T1= 348.62 g) as shown in Table 2.

Table 2. Yield of the onion bulb subjected to different planting dates.

Treatment	Planting date	Weight (g)
T1	November 07	348 62 a
T2	November 15	292 87 b
T3	November 22	338 59 ab
T4	November 29	193 87 c
T5	December 06	153 19 c

Averages followed by same letters indicate significant differences between treatments (Tukey; $p\leq 0.5$).

According to McClung and Davis (2010), temperature is a determining factor in plant development, which includes ranges where the plant is not stressed. Based on this criterion, this research relates the weight of the onion with different parameters of temperature, finding that there are some that do influence the results obtained. The behavior of temperature during the development of the experiment is shown in Figure 2. In the third treatment the lowest average maximum temperatures occurred with 30.03 °C, while the lowest occurred on the third date.

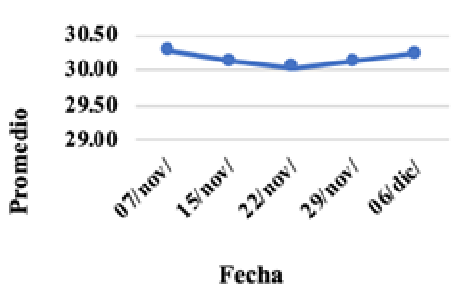

Figure 2. Average maximum temperature in the development of onion crop. Elaboration with data from CONAGUA (2015).

On the other hand, in Figure 3, it is shown that the minimum temperatures decreased according to the date of the treatments, finding that for treatment 1, the average minimum temperature was 13.06 °C, while for treatment five it was 12.27 °C. With respect to Figure 4, the data show that the thermal oscillation for each treatment was different, finding that it had the lowest values first, presenting a tendency to increase the thermal oscillation for each treatment, according to the date of transplantation.

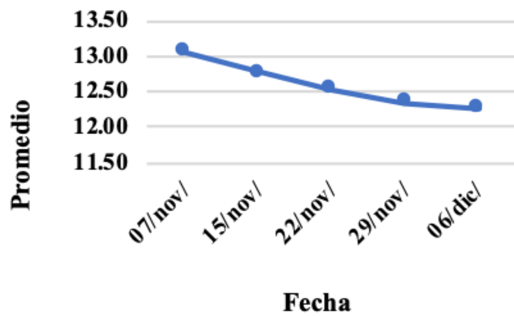

Figure 3. Average minimum temperature in the development of onion crop. Elaboration with data from CONAGUA (2015).

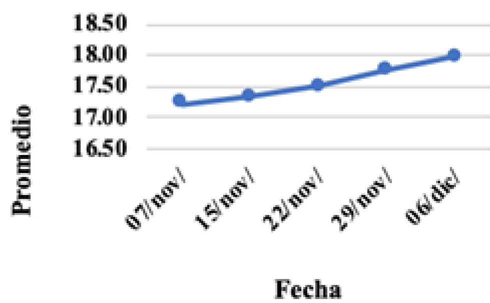

Figure 4. Average thermal oscillation of temperature in the development of onion crop. Elaboration with data from CONAGUA (2015).

Data on temperature parameters were analyzed: average maximum temperature, average minimum temperature, average temperature and thermal oscillation. When doing the linear regression analysis, it was found that all four parameters were statistically significant. However, the values of the coefficient of determination are higher in the parameters of thermal oscillation and the variation of the average minimum temperatures.

Regarding the thermal oscillation, the coefficient of determination was 0.84, that is, this dependent variable explains 84% of the behavior of the bulb weight. In this regard, Steer (1980) found that the development of the bulb was slower when the difference between the night temperature was 15 °C and when the oscillation was 5 °C. One of the reasons for this may be that the onion is very sensitive to the daily variation of temperature, since during the early hours of the morning the plant is upright, while at noon, during the maximum temperatures, the plant bends its leaves, which might imply loss of energy, then, the higher the thermal oscillation, the greater the movement of the leaves (Figure 5).

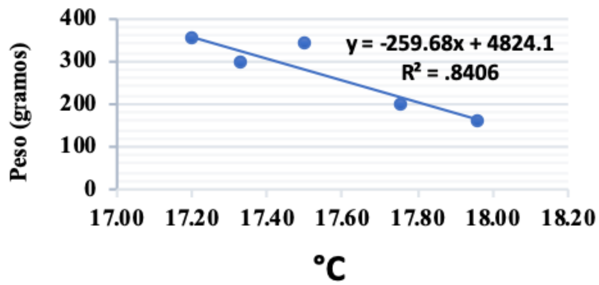

Figure 5. Influence of thermal oscillation on onion yield in Sinaloa. Elaboration with data on the temperature from CONAGUA (2018).

Plants that developed under higher maximum temperatures had a lower development, because the high temperatures shortened the life cycle, in this regard, Lescay and Moya (2006) found that the yield of the onion decreases when the temperature increases. On the other hand, some plant species adjust the angle of the leaf in relation to the sun rays at noon, when there is the greatest warming (Jones and Rotenberg, 2001). The plant performs this action to protect against water stress. However, by reducing the interception of light, it affects the ability to maintain high rates of CO_2 assimilation during this period in well-watered plants (Pastenes *et al*., 2004). This then affects the photosynthetic activity and with it the development of the onion plant.

The other temperature parameter with a high coefficient of determination was the variation of the minimum temperature. It is observed that as the minimum temperature values increase, there is also an increase in yields.

This may be related to the fact that the earlier transplanted onions had a better development during the period before bulb formation, as they were more distant from the minimum temperature for leaf development, which is 6 to 7 °C according to Kalbarczyk and Kakbarczyc (2015); that is, the plants had more favorable conditions for leaf development. In this regard, Lancaser *et al*. (1996) points out that in their study, bulb growth was related to the thermal time accumulated before bulb formation. In contrast, in onions that were transplanted at later dates, this stage of development occurred when temperatures were closer to the critical point of development.

The onions transplanted during the first dates had an adequate development before bulb formation, accumulating nutrients in their leaves. This allows the onions to be in favorable conditions when they perceive the decrease in temperature, which indicates that the plant must enter a period of dormancy to withstand the cold.

Faced with this situation, the plant begins the process of bulb formation. In this regard, Thomashow (1999) indicates that acclimatization to the cold involves many biochemical and physiological changes including the modification of the composition of the membrane, increase in the content of soluble proteins, increase in the levels of proteins and sugars that allow the plant to resist freezing. In contrast, plants that were planted later receive such a signal when they have not yet accumulated sufficient nutrients in their leaves, so the bulb formation process is deficient.

The proper formation of leaves before and during bulb formation is very important, since the translocation of nutrients from the green leaf to the bulb is decisive in the weight of the onion (López *et al*., 2017). Added to this, in the last stage of the formation of the bulb, the plant is under high temperature conditions, which accelerates the ripening process, because the accumulation of heat is done in less time than in the onions transplanted earlier. In this regard, Ikeda *et al*. (2019) point out that in the study they carried out, bulb growth stopped at relatively high temperatures.

Bulb growth is also influenced by photoperiod and could be considered to have an effect that combines with temperature (Chope *et al*., 2012). In this case, it is difficult to estimate what the determining factor is, because the place where this experiment was developed, the temperature is highly dependent on the length of the day. In this regard, Brewster (2008) considers that the influence of these two factors will depend on the varieties of onion that are on the market.

The differences in weight found between the treatments can also be applied to the diameter of the onion, because when performing the correlation analysis between the weight and the diameter of the onion, it was observed that there was statistical significance in the relationship, as can be seen in the following section.

Onion diameter and weight relationship

When performing the analysis of variance of correlation between the weight and diameter of the onion, it was observed that there was statistical significance in the regression with a critical value of F of 9.169E-144. It was also found that the correlation between the weight and diameter of the onion was 0.943; that is, 94% of the behavior of one variable depends on the other. In addition, the value of the slope (b) indicates that for each centimeter of the diameter of the onion, it increases 98.6 g in weight as seen in Figure 6.

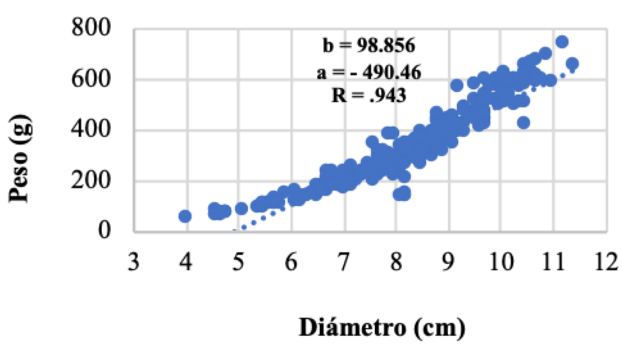

Figure 6. Relationship between weight and diameter of the onion. Degrees Brix in the onion bulb.

Grades Brix in the onion bulb

The Kruskal-Wallis nonparametric statistical test applied to analyze the difference between the treatments with respect to the content of °Brix indicates that there was a statistically significant difference.

From the above, a comparison of ranges was made using the Dunn procedure, finding that the lowest concentration of °Brix was obtained in treatment five, which is composed of the onions that were transplanted later. On the contrary, the one with the highest concentration of °Brix was sown on intermediate dates.

The plants with the lowest concentration of °Brix are those transplanted in recent dates, which is why in the last stage of their development the highest temperatures occurred. In contrast, the intermediate-date treatment was developed under conditions of lower temperatures (Table 3). It also had the highest values of °Brix, this may be because the onion like other plant species reacts to low temperatures, concentrating sugars as a defense mechanism to acclimatize to temperatures that can reach the freezing point (Thomashow, 1999).

Table 3. Multiple comparisons by pairs using Dunn's procedure-bilateral test.

Sample	Frequency	Sum of the ranges	Mean of the ranges	Groups
November 07	75	14 441	192.55	C
November 15	78	14 683.5	188.25	C
November 22	58	14 353	247.47	D
November 29	59	6 642.5	112.59	B
December 06	57	3 508	61.54	A

It was found that as the maximum temperature increases, the concentration of °Brix decreases, finding that the independent variable determines the behavior of yield by 24% and that for every 0.1 °C that the maximum temperature increases, the concentration decreases by 36° Brix.

Thermal constant

The development of the onion was affected by the speed of accumulation of the heat units, finding that one of the consequences of the increase in temperature, during the development period between transplantation and leaf bending, was shorter as the onion was transplanted later. The onions transplanted on the first date accumulated a thermal constant of 2 621.88 °C, they had a development period that lasted 120 days, while the treatments where the onions were transplanted later had a period of 110 days, accumulating an average of 2 359.08 °C.

One of the reasons why the period of development of the onion was shorter in the treatments transplanted later may be because temperatures increased at the end of the vegetative cycle, which accelerated the ripening of the plant.

The treatment that was transplanted first presents the highest temperature values, because, in the early stages of development of the plant, the temperature was higher than in the rest of the treatments, which could affect its development by lasting longer with warm temperatures before reaching the bulb formation. This suggests that the thermal constant has a differentiated influence on the different stages of onion development (Table 4).

Table 4. Planting date, days to harvest and accumulative temperature for the transplanted onion every week.

Transplanting date	Days to harvest	Maximum	Minimum	Average	Thermal oscillation
	Accumulative temperature (°C)				
November 07	120	3 663.01	1 580.75	2 621.88	2 082.26
November 15	115	3 493.46	1 482.86	2 488.16	2 010.6
November 22	110	3 333.72	1 390.74	2 362.23	1 942.98
November 29	110	3 342.93	1 371.18	2 357.05	1 971.74
December 06	110	3 356.13	1 362.03	2 359.08	1 994.1

Bromatological analysis

Although no statistically significant differences were found with respect to the bromatological analysis, it is observed that the treatment that was developed under the lowest temperatures had the highest concentration of proteins, which may also be related to the reaction that some plant species have to concentrate proteins in their cells as a defense mechanism against low temperatures. This process can contribute to the increase of dry matter in the onion and therefore in the yield.

The results of the bromatological analyses regarding fiber, protein and ashes (Table 5) did not find significant difference in any of the cases and it can be observed that the amount is very similar in each of them, that means that, although the date and density in the crop is modified, this will not modify its composition at least in terms of the characteristics evaluated.

Table 5. Results of bromatological analysis.

Treatment	Fiber	Protein	Ash
November 7	5.86 a	7.69 a	5.92 a
November 15	6.16 a	8.95 a	5.44 a
November 22	6.09 a	9.53 a	5.87 a
November 22	6.57 a	8.35 a	5.77 a
December 6	6.23 a	6.85 a	5.26 a

Values with the same letter are statistically equal, significance of 0.05.

After applying the formula for each compound, the amount of CO_2 fixed per hectare of each of the treatments was determined, finding that they are statistically similar, as reported in a research conducted in Zinacantepec, State of Mexico by Paulino (2013), the amount of CO_2 fixed in the onion crop is higher than the carbon fixed of pine in the forests, which corresponds to 0.847 t ha^{-1} per year, this gives an idea of the potential of the crop as a carbon fixer, however the same author reported that the tropical rainforest fixed 32.34 tons of CO_2 per year, the potato crop 30.08 tons of CO_2 per year , being these much higher in terms of carbon capture compared to the onion crop.

Although there were no statistically significant differences between the treatments (Table 6) in reference to carbon dioxide fixation, a higher concentration is observed in treatment three, which was developed under lower temperature conditions, having a value of 1.56 CO_2 (t CO_2 eq ha^{-1}). This may also be related to the low temperatures under which the third treatment was developed. The increase in CO_2 may be an indirect consequence of the low temperatures that in turn caused the increase in proteins and sugars and as a result there was an increase in carbon.

Table 6. Equivalent of total Co_2 fixation of the plant.

Treatment	CO_2(t CO_2 eq ha^{-1})
November 07	1.28 a
November 15	1.43 a
November 22	1.56 a
November 29	1.52 a
December 06	1.44 a

Values with the same letter are statistically equal, significance of 0.05.

Conclusions

The diameter and weight of the onion are highly correlated, so that, by knowing the diameter of the bulb in the field, it is possible to have an estimate of the expected yield on an estate. Onion plants that developed under conditions of lower temperatures had a higher concentration of degrees Brix, which may be due to the fact the onion, as other plant species, reacts to low temperatures, concentrating sugars as a defense mechanism to acclimatize to low temperatures, which allows it to withstand temperatures that reach the freezing point.

Plants that were transplanted later had a shorter life span, which may be due to the fact that temperatures increased at the end of the vegetative cycle, which accelerated the ripening of the plant. The results of the bromatological analyses regarding fiber, protein and ashes do not show significant difference in any of the cases and it can be observed that the amount is very similar in each of them, meaning that, although the date and density in the cultivation is modified, this will not modify its composition at least in terms of the characteristics that were evaluated.

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